USE OF BANDING DATA IN MIGRATORY GAME BIRD RESEARCH AND MANAGEMENT

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
Special Scientific Report—Wildlife No. 154

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by

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Bureau of Sport Fisheries and Wildlife
Special Scientific Report--Wildlife No. 154
Washington, D.C. . 1972

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents
Stock Number 2410-0319

CONTENTS

INTRODUCTION

The purpose of this paper is to discuss the role of banding data in migratory game bird management. The procedures followed in analyzing these data and the assumptions made are also outlined. This information is desired not only to better understand and justify expensive banding programs, but also to provide guidance to those wishing to analyze banding data. This understanding is essential, not only to effectively use the resulting data, but also to make correct decisions in the field while banding. A realization of how banding data are used emphasizes the importance of many details, such as accurate age and sex determinations in the field and the correct reporting of this information on banding schedules.

The basic assumptions that underlie various procedures are discussed; however, no mention is made of the very important subject of sampling error, which is a separate problem. Methods of calculating various estimates are illustrated with specific examples. The procedures are not complicated and do not require an extensive background in mathematics.

Although this report discusses most of the uses that have been made of game bird banding data to investigate management problems, it does not include uses relating to less applied subjects such as migrational homing, trap response and similar subjects. The procedures outlined are those that have been used at the Migratory Bird Populations Station of the Bureau of Sport Fisheries and Wildlife during the past decade. Some of these procedures are the same as those followed by Hickey (1952) and Ricker (1958), while others which deal largely with weighted band recoveries were developed at the Station.

Why do we band migratory game birds? Simply stated, it is to obtain information on characteristics of populations which can be used for management. Basically, there are three major characteristics (each with many ramifications) of game bird populations revealed by banding data: (1) the distribution (and derivation) of the hunting kill, (2) rate of hunting kill, and (3) estimates of mortality rates from all causes of death once the birds are old enough to be banded.

USE OF BANDING DATA TO DETERMINE THE DISTRIBUTION (AND DERIVATION) OF THE HUNTING KILL

Distribution of the hunting kill relating to summer and winter areas

It is important to know the distribution of the hunting kill relating to various summer and winter populations. For example, the results of the extensive waterfowl breeding ground surveys carried out in North America would have little application if we did not know the harvest areas influenced by various production areas. This type of information is illustrated in Example 1 (Lensink, 1964) which shows the distribution of direct recoveries of mallard locals banded in various breeding population survey strata. Note that adjacent survey strata sometimes make markedly different contributions to the same flyway. For example, stratum 26 in Alberta makes a relatively smaller contribution to the Mississippi Flyway and a greater contribution to the Pacific Flyway than does the adjacent stratum 27. It is also significant in Example 1 to note the extent to which different survey strata in various parts of the breeding range all contribute birds to several flyways. This implies that shooting pressure in one flyway can affect ducks breeding in an area which also supplies birds to another flyway.

It is also important to understand the distribution of the hunting kill relating to various wintering populations. This is illustrated in Example 2 which shows the logic for having different regulations in the Columbia Basin of the Pacific Flyway than in the Mississippi Flyway during the 1964 season. That year the daily bag limit in the Columbia Basin was 8, of which 4 had to be mallards, while in the Mississippi Flyway the daily bag limit was 4, of which only 2 could be mallards. Furthermore, the hunting season was more than twice as long in the Columbia Basin than in the Mississippi Flyway. Example 2 summarizes the distribution of the hunting kill during the 1964-65 hunting season on mallards banded in the Columbia Basin portion of Washington, and in Arkansas, the heart of the Mississippi Flyway population. Striking differences are evident. The kill of Columbia Basin birds was concentrated in the wintering area, and there was relatively little shooting pressure during migration. This is probably due to a relatively short migration route through unpopulated areas. In contrast, birds banded in Arkansas were harvested to a substantial degree in production areas in the Pacific Provinces of Canada, across the northern half of the Central Flyway, and extensively throughout the entire Mississippi Flyway. Mississippi Flyway birds are subjected to hunting mortality over a much wider area than are Columbia Basin birds. It is noteworthy that band recovery rates (to be discussed at length later) shown in Example 2 were approximately the same for both populations in spite of more liberal hunting regulations in the Columbia Basin. The substantial differences in the characteristics of these two populations illustrate why different regulations are logical. The effective management of summer and winter populations requires information on the distribution of the harvest relating to each population that only band recoveries can supply.

Derivation of the hunting kill in various harvest areas

Knowledge of the proportion of the kill in a harvest area that relates to various summer and/or winter populations also has management significance. Example 3 illustrates a situation where two important black duck harvest areas derive their kill from quite different production areas. A similar type of analysis resulted in the definition of the three mourning dove management units (Kiel, 1959). These units were defined so that each unit essentially harvested only mourning doves produced in that unit.

If the same fraction of all populations was banded, it would be possible to merely look at the banding area derivation of birds recovered in each harvest area to determine the relative importance of various areas. However, this condition is never met. Example 4 shows a typical set of banding data where three wintering populations of black ducks are represented by quite different amounts of banding data. In order to correct for this disproportionate banding effort, it is necessary to calculate weighting factors that can be applied to recoveries from each area to adjust for the varying numbers of birds that they represent. Two methods of calculating weighting factors have been used. The first, shown in Example 4, permits the use of all recoveries from shot birds, providing that recoveries during the second and subsequent hunting seasons after banding have the same distribution pattern as recoveries during the first season after banding. The weighting factor applied to recoveries from each wintering area is calculated as follows: the number of recoveries is divided into the average population value to obtain the "population per recovery" as shown in line C. To recognize differences in shooting pressure between populations, the "population per recovery" is multiplied by the first hunting season recovery rate (discussed later) to yield the "kill per recovery" as shown in the last line. This is the value that is multiplied by the number of recoveries that actually occurred from the area to obtain a weighted value which places the recoveries in proper relationship to one another.

The second method for calculating weighting factors is to simply divide the number of birds banded in each banding area into the average population for the area. The resulting value is then used to weight each recovery from the area. It is not necessary to allow for differences in shooting pressure in calculating the weighting factors by this method because there will be relatively more recoveries where shooting pressure is heavy than where it is light. Example 5 illustrates how weighting factors were calculated in this way to aid in defining mourning dove management units. Although more straightforward, this second approach has a disadvantage in that to avoid introducing biased estimates, only recoveries occurring the first year after banding should be considered. This is necessary because recovery rates must properly represent any difference that may exist between areas in the proportion of the population that is harvested. For example: 1,000 birds were banded in Area A in 1965, and 1,000 in Area B in 1970. Recoveries

through the 1970 hunting season total 100 from each area; however, in Area A, 50 recoveries were in the first year after banding, and the remainder in subsequent years, and in Area B, all 100 recoveries were in the first year after banding. In this case the use of 100 recoveries from each area would suggest equal harvest rates for both; however, the difference in first-hunting season recovery rates suggests that the harvest rate for Area B is twice that for Area A. Therefore, first-year recoveries would be the appropriate ones to use in determining weighted distribution. The first method of weighting, involving two steps, permits more data to be used in a comparable manner than the second but makes the assumption that recoveries occurring the second, third and later years after banding, continue to reflect the characteristics of the population originally sampled.

The use of weighted band recoveries depends on two major assumptions: (1) all populations contributing significantly to the harvest areas under consideration are represented by banded birds, and (2) the relative size of the populations represented by banded samples is known. Indexes to population size can be quite crude and still be useful.

The manner in which weighting factors are applied to recovery data to obtain estimates of the derivation and relative size of the kill is illustrated using data from immature mallards banded throughout their breeding range, 1966 through 1968, and taken in Arkansas and Washington (Example 6). The actual number of recoveries is multiplied by the weighting factor to obtain a weighted recovery total. All estimates of the derivation and relative size of the kill (in %) are based on the weighted recovery totals.

Geographic distribution of the hunting kill

Weighted band recoveries also furnish information on the relative size of the hunting kill in various areas. Note in Example 6 that the total weighted recoveries (Arkansas--112,671 and Washington--84,559) reflect the relative size of the kill in each area. These data indicate that the immature mallard kill in Arkansas would be expected to be about 33 percent greater than that in Washington. This is not only valuable by itself but also furnishes insight on the accuracy of the population surveys used as a basis for calculating weighting factors. This is illustrated in Example 7 which compares the distribution of the black duck kill based on three independent sources of information:
(1) weighted band recoveries from black ducks banded in the summer,
(2) weighted band recoveries from black ducks banded in the winter, and
(3) the Bureau's mail questionnaire survey of waterfowl hunters, which is believed to be reasonably correct. Two of these sources of information agree, suggesting that slightly more than 60 percent of the black duck kill occurs in the Atlantic Flyway. Data from summer bandings suggest a much lower kill in the Mississippi Flyway than indicated by the other agencies. The most plausible explanation for this discrepancy

is that the number of black ducks breeding in western Ontario is larger than population surveys indicated, and therefore, recoveries from this area which occur almost entirely in the Mississippi Flyway were not given sufficient weight. Weighted band recoveries also sometimes point the finger at populations not represented by banded birds. For example, weighted canvasback recoveries from banding in winter areas indicate a kill in Texas that is much lower than that suggested by summer bandings or mail surveys. The reason for this is evident when it is noted that no canvasbacks wintering in Texas or Mexico have been banded. Banding provides the thread that shows how well population and kill data hold together.

When band recoveries furnish information on the distribution of the kill, and the size of the kill in at least one harvest area is known, it is possible to estimate the size of the kill in the areas lacking kill estimates. For example, prior to the beginning of mail questionnaire surveys in Canada, it was necessary to estimate the size of the mallard kill in Canada by relating the distribution of weighted band recoveries between the United States and Canada to kill estimates in the United States. Banding yielded estimates of the proportion of the total continental kill occurring in Canada (see Example 1). Since the size of the kill in the United States was known, it was possible to estimate the kill in Canada. It is noteworthy that once kill estimates based on mail survey data became available from Canada, they agreed very well in general magnitude with those obtained earlier through the use of banding and kill survey results in the United States.

Banding also has been used to point out the relative importance of various harvest areas for specific populations. In all instances where recoveries from two or more areas are compared to determine the distribution of the kill, the assumption is made that the proportion of the banded birds taken by hunters that are reported to the Banding Laboratory is the same in all areas. Since only about one-third of the banded ducks taken are reported (Martinson, 1966b) there is a potential for biased estimates due to regional or local differences in band reporting rates.

Example 8 shows the distribution of band recoveries from Canada geese relating to the Mississippi Valley Canada goose flock banded in southern Illinois. The data suggest that Wisconsin was by far the greatest harvester of this flock during 1959 through 1963, even though harvest quotas assigned to these States should have resulted in a substantially greater harvest in Illinois. In this case there is evidence (Geis, 1972) that the relative size of the harvest in Illinois based on band recoveries is minimized due to a relatively low band reporting rate in southern Illinois.

In summary, banding provides the only source of information on the relationship of harvest areas to various production and wintering areas and vice versa. By relating production and wintering areas to harvest

areas, weighted band recoveries provide important information about the accuracy of population data and the adequacy of banding programs.

USE OF BANDING DATA TO MEASURE RATE OF KILL

Definition of terms

Before explaining uses of banding data to determine harvest rates, it is appropriate to define the various rates referred to in discussing banding data.

1. Band Recovery Rate.--The proportion of banded birds that are recovered and reported to the Banding Laboratory. For example, if 1,000 birds are banded of which 100 are recovered and reported, there is a 10 percent recovery rate. Band recovery rate may be related to a variety of specific situations. Some commonly applied qualifications of band recovery rates are as follows:

    a. Direct recovery rate.--Relates only to recoveries that occurred relatively soon after banding and before a change in direction of movement due to migration has occurred. For example, for birds banded during summer and fall, direct recoveries are those occurring during the first hunting season after banding. For bandings in winter, after the end of the hunting season, recoveries during the first hunting season after banding are not direct recoveries since the birds had begun a second migratory cycle before the recoveries occurred.

    b. Indirect recoveries.--All recoveries other than direct recoveries. These are called "indirect" because they do not occur in an area to which the birds move directly after banding.

    c. Hunting season recoveries (first, second, third, etc.).--These terms relate to the hunting season after banding during which recoveries occurred. First hunting season recoveries refer to birds recovered during the first season following banding, second hunting season recoveries refer to those taken during the second season, etc. This terminology is preferred over "direct" and "indirect" recoveries since it is more explicit in its meaning.

2. Reporting Rate.--The proportion of bands taken by hunters that is reported to the Banding Laboratory. For example, if half the banded birds taken by hunters are reported, the reporting rate is 50 percent.

3. Harvest Rate.--The proportion of a population that is harvested. This is the recovery rate divided by the reporting rate. If the recovery rate was 10 percent and half the banded birds taken were reported, the harvest rate would be 20 percent.

4. Kill Rate.--The harvest rate with the addition of estimated crippling loss. It is an estimate of the proportion of the population dying directly as a result of hunting.

5. Mortality Rate.--The proportion of a population dying from all causes during a specified time period. Thus, if 1,000 birds are alive at the beginning of an annual period and 600 die as a result of hunting, disease, accidents, etc., before the next annual period starts, the annual mortality rate would be 60 percent. Most mortality rate estimates relate to an annual period. For life tables of game birds the period usually runs from the beginning of one hunting season to the beginning of the next; however, when based on the relative recovery rate method (to be discussed later), the interval between two banding periods is used, regardless of its length.

6. Relative Recovery Rate.--The extent to which the recovery rate for one age, sex, or population exceeds that for another. One of its uses is to express relative differences in the likelihood of being shot. Thus, if immature ducks in a population have a first-hunting season recovery rate of 10 percent, while adults have a first-hunting season recovery rate of 5 percent, the relative recovery rate would be 10 ÷ 5 or 2 indicating that immatures are twice as likely to be shot as adults. This assumes an equal mortality rate between the time of banding and the beginning of the hunting season for the two banded samples being compared.

Evaluation of regulations

A comparison of band recovery rates under various hunting regulations may indicate the effect of regulations on the rate of kill. Example 9 presents canvasback and ringneck band recovery rates under various hunting regulations. These data indicate that recovery rate generally changed in the same direction as season length and bag limit. An interesting exception was 1958 in New York when a very high recovery rate for canvasbacks occurred despite a marked reduction in the daily bag limit. During 1958 New York selected a split season with the second half set unusually late. Because of cold weather during the second portion of the season, most water areas froze; however, the deep lakes where canvasbacks concentrated were open. Unusually heavy shooting pressure on these unfrozen lakes resulted in a high kill. The ringneck data indicate that in 9 out of 10 comparisons, band recovery rates changed in the same direction as hunting restrictions. Note that no comparison was made for South Carolina between recovery rates observed in 1931 with those observed in the next period having data, 1940 through 1941. It is advisable to confine comparisons of band recovery rates to adjacent time periods. Data from nonadjacent time periods may not be comparable because of changes in band reporting rates and habitat factors affecting vulnerability of the birds to shooting.

464-285 O - 72 - 2

Determination of the age composition in the population

To understand the implications of the age composition of the duck kill as indicated by wing collection surveys in the United States and Canada, it is necessary to know the extent to which immature ducks are more likely to be shot than adults. A comparison of band recovery rates from preseason banding of immatures and adults provides this information. For example, if first season recovery rates are 15 percent for immatures and 10 percent for adults, then immatures are 1.5 times more likely to be shot than adults. If the age ratio in the kill, as indicated by a wing collection survey, is 1.5 immatures per adult, then the preseason population must have contained 1 immature per adult. The age ratio in the preseason population is the age ratio in the kill divided by the factor indicating the extent to which immature birds were more likely to be shot than adults (relative recovery rate). In this example: 1.5 divided by 1.5 equals 1. This information is essential in order to determine whether current annual mortality rates are being counterbalanced by production. Thus, it provides insight into population trends.

Example 10 shows how recovery rates were applied to age ratios observed in the kill in the San Luis Valley of Colorado to adjust for differential vulnerability. In 1963 habitat conditions were poor in this area, and it was anticipated that a low age ratio would be found. Since immatures and adults had the same first season recovery rate, the age ratio observed in the kill was the same as the age ratio in the preseason population. The next year habitat conditions were also poor; however, the age ratio observed in the kill was very much higher than the previous year. Comparisons of recovery rates from the two age groups explain this change. The recovery rate for immature mallards was 1.4 times greater than that from adults. When this value was divided into the 1.21 immature/adult age ratio observed in the kill, the estimated age ratio in the population (0.86 immature/adult) was similar to that of the previous year.

The age composition of the kill and relative recovery rates from preseason banding of adults and immatures are used each year to estimate production rates for the mallard and wood duck in North America. This procedure depends on a representative sample of each age being banded. However, it is not necessary that the age composition of the banded sample be the same as in the population since only recovery rates are involved in the calculations.

Measuring sex differences in shooting pressure

Band recovery rates indicate the extent to which one sex is more likely to be shot than the other. This information makes it possible to judge the implications of unbalanced sex ratios that often are observed in the hunting kill. Band recovery rates can be used to determine the extent to which a sex ratio in the kill is distorted in the same manner used to understand age differences. Knowledge about the

sex composition of the population aids in understanding its reproductive potential and in interpreting breeding population survey data.

Example 11 illustrates the use of band recovery rates from male and female mallards to estimate the sex composition in populations at the time of banding. Note that males consistently had a higher first hunting season recovery rate than females. Care must be taken in interpreting such data. Higher recovery rates for males indicate that they are more likely to be shot the first hunting season after banding than females. However, the reason for this difference could be due to (1) selectivity for males on the part of hunters, (2) greater vulnerability of males to shooting, or (3) greater non-hunting mortality of females between the time of banding and the next hunting season. With preseason banding, non-hunting mortality is not significant because the interval between banding and the hunting season is short. With postseason (winter) banding, however, the interval between banding and the next hunting season is six months or more. Non-hunting mortality of females undoubtedly contributes heavily to the greater recovery rates of males than females banded postseason. Regardless of the reason for a difference in the likelihood of males or females being shot, band recovery rates indicate the extent of this difference and, therefore, permit an estimate of the sex composition of the population <u>at time of banding</u> based on the sex composition in the kill.

<u>Species differences in shooting pressure</u>

Band recovery rates indicate the extent to which differences exist among species in the shooting pressure they receive. For example, they clearly indicate that harvest rate is relatively low for blue-winged teal and high for canvasbacks. Thus, a special early season is conceivable for teal while canvasbacks require special restrictive regulations for their protection.

<u>Geographic differences in shooting pressure within a species</u>

One of the challenges in migratory game bird management is to set regulations that provide the maximum possible recreational use of the resource without permitting an excessive kill. Band recovery rates provide a measure of differences in shooting pressure exerted against different population units of a species. Note the marked differences in recovery rates and associated mortality rates for various populations of wintering mallards shown in Example 12. Populations in southeastern Colorado and eastern South Dakota had very low first-hunting-season recovery rates, while those in western Oregon, eastern Nebraska and Oklahoma were associated with high band recovery rates.

<u>Estimating the proportion of a population removed by hunting</u>

Band recovery rates provide a basis for estimating the proportion of a population dying each year due to shooting. This is done by adjusting the recovery rate for non-reported bands and crippling loss.

This is illustrated in Example 13 for canvasbacks banded during the summer in Manitoba and Saskatchewan in 1953-57. The observed direct recovery rate, adjusted for non-reported bands and crippling loss, yielded a kill rate of .49. In other words, about half of the young canvasbacks alive at the time the sample was banded were killed during the next hunting season. The kill rate can be compared to the total mortality rate (77%, Geis, 1959) to indicate that about 64 percent of all deaths were due to shooting. If the kill rate and mortality rate estimates had been based on postseason winter banding, these data might indicate a lower proportion of losses due to hunting. This is because non-hunting mortality reduces the number of birds entering the hunting season, leaving fewer birds to be killed by hunting. Also, adults are normally less vulnerable to shooting than young birds entering their first hunting season. The band recovery rate is basic to determining the importance of hunting as a mortality factor.

Population estimates

Band recovery rates serve as a basis for estimating population levels when information on the size of the harvest also is available. For example, if band recovery rates adjusted for non-reported bands indicate that 10 percent of the population is harvested and the harvest is known to be 10,000, then it must have been taken from a population that totaled 100,000. Following this approach, annual estimates have been made in recent years for the mallard and wood duck. Example 14 presents wood duck data which was used to estimate pre-hunting season populations for the years 1963-1965. Estimates such as this not only depend on recovery rate and reporting rate information but also on harvest and wing collection surveys to provide information on the size of the harvest by age group. It is necessary to break down the data by age because adults and immatures often have different harvest rates. This approach has provided our only source of information concerning wood duck population levels. Because of the habitat occupied by this species, direct counts by conventional survey methods are not feasible. Note that the analysis associated with obtaining indirect population estimates provides other useful information such as the age ratio in the preseason population. It also provides an estimate of annual mortality rates by comparing the total population for one year with the adult population of the following year. Because of the many factors upon which an indirect population estimate depends, it is advisable to compare it with an estimate of annual mortality rate in order to check the plausibility of the results. This can be done in Example 14 where the 1963 preseason total population of 2,326,593 can be related to 1,042,653 adults prior to the 1964 season - indicating a reasonable 55 percent mortality rate.

Example 15 presents a population estimate for mallards associated with the San Luis Valley of Colorado using the same method as for the wood duck. An estimate such as this relating to a specific area must be interpreted with caution because the movement of banded ducks away

from the Valley or unbanded ducks into it both tend to cause an inflated estimate.

Like the wood duck, a number of species of migratory game birds cannot be adequately counted by conventional population surveys. Often reasonably reliable kill information is available for these species, and if enough banding could be done to measure the harvest rate, it would be possible to estimate population size. This approach does not require that all populations be represented by banding, only that sufficient banding be done to provide a reliable estimate of the harvest rate. In those instances where all significant populations are represented by banding and the distribution of the kill is known, it is theoretically possible to calculate the size of populations associated with various portions of the breeding and wintering range. Using real data, a computer would be required to make the calculations. This approach is illustrated, however, in Example 16 with hypothetical data relating to only two banding and two harvest areas. In this example simultaneous equations are set up with as many equations as there are harvest areas, each having as many unknowns as there are banding areas. In each equation the total harvest in the area equals the sum of the harvests contributed by each banding area as expressed by the harvest rate times the unknown population value for the area.

In this discussion of indirect population estimates, both harvest rates and band recovery rates have been referred to as serving as a basis for the estimates. When actual harvest rates are used, the resulting estimates indicate the actual size of the population. However, if estimates of band reporting rates are not available, band recovery rates may be used to obtain an index to population levels. This index will be inflated to the extent that banded birds taken by hunters are not reported. The use of band recovery rate and kill statistics to obtain population estimates is an important use of banding data that will, no doubt, have greater application in future years than it has in the past. Lincoln (1930) emphasized the importance of such population estimates more than forty years ago, and it is ironic that only recently have we been able to heed his advice.

A second approach to making indirect population estimates based on banding data is theoretically possible by determining the proportion of the population marked when a known number of birds is banded. This approach would have an advantage over the one that has been followed in that it would not require information on the size of the kill or band reporting rates. However, it does require an accurate measure of the proportion of the population banded by a specific banding program. The wing collection survey is a potential source of this information. However, until the extent of the bias caused by people utilizing wing collection envelopes to report bands can be evaluated, this procedure cannot be followed.

Effect of harvest rate on annual mortality rates

Band recovery rates permit the examination of perhaps the most critical question in migratory game bird management, i.e., the extent to which shooting pressure affects total annual mortality rates. If hunting mortality merely replaces non-hunting mortality, increases in the kill made possible by more liberal regulations would constitute good management. On the other hand, increasing the harvest rate may increase the annual mortality rate and, therefore, have an effect on breeding population levels. The relationship between recovery rates and annual mortality rates was first examined by Hickey (1952) and is illustrated here with data from preseason-banded immature black ducks (Example 17). These data indicate that populations associated with high shooting pressures (as indicated by high first season recovery rates) have much higher annual rates of mortality than those associated with low shooting pressures. The relationship between shooting pressure and mortality rate estimates will be discussed later after a review of methods for estimating mortality rates.

ESTIMATING RATES OF MORTALITY

The third major use of banding data is to estimate rates of mortality. This information is important for several reasons. When used in conjunction with information on production, it serves as a basis for determining the status of populations. Knowledge concerning mortality rates is also necessary to evaluate the importance of hunting as a mortality factor. As pointed out in the previous section, unless shooting mortality affects total mortality rates, there is little justification for adjusting hunting regulations in order to change population levels.

Relative recovery rate method

There are a number of ways in which estimates of mortality can be obtained. Lauckhart (1956) showed how the mortality rates of mallards can be measured by comparing recovery rates during the same hunting season from samples of the population that were banded at different times. Ricker (1958) described a similar approach in studying fish populations. This approach is often called the relative recovery rate method because it is based on a comparison of recovery rates; it assumes that if all birds banded during one period were still alive during a second banding period, they would have the same recovery rate as birds banded during the second period. A difference in the recovery rates reflects mortality that occurred between the banding periods.

Example 18 illustrates the use of this method with 1967 hunting season recovery rates from adult and immature mourning doves banded during June, July and August of 1966 and 1967 in each of the three management units (Reeves, 1969). The annual survival rate is estimated

by comparing recovery rates during the 1967 season from samples banded in 1966 and 1967. The extent to which the sample banded in 1966 had a lower recovery rate in 1967 than the sample banded in 1967 reflects the mortality rate in the population between the 1966 and 1967 banding periods. In order to estimate the annual mortality rate for immature doves, it was necessary to compare the second hunting season recovery rate from immature doves banded in 1966 with the first year recovery rate from adult doves banded in 1967. The first season recovery rate from immatures should not be compared with second year recovery rates because first year recovery rates from immatures are inflated due to the greater vulnerability of young birds. The second season recovery rates relate to adults at time of recovery and should be compared with recovery rates from another sample of adults.

When using the relative recovery rate method, it is assumed that the same population is marked during each banding period and, therefore, the survivors from all banded samples are harvested at the same rate during later hunting seasons.

The relative recovery rate method can be used to determine mortality rates during any length interval (defined when the birds are banded that yield the two rates that are compared). The black duck recovery rates presented in Example 19 and graphed in Example 20 show that if samples of the population are marked at various times during the year, differences in rates of mortality within the year can be studied. These data show that recovery rates from black ducks banded during the fall changed more rapidly than samples banded at other times, thus suggesting a greater rate of mortality at this time than at other times of the year. The two rates, each incased in a box, in Example 20 are not comparable with the others because they relate to birds banded while immature. Since immature birds have a higher first-year mortality rate than adults, it would be expected that they would have a depressed second hunting season recovery rate. These points are included to illustrate the change in recovery rates that occurred between two periods in the fall and thus the mortality rate during that period.

Example 21 shows how recovery rates can be used to deduce if restrictive hunting regulations influence the survival of redheads. Here recovery rates in the fifth hunting season after banding are compared to see if there is any indication that redheads banded in 1960 and recovered in 1964, a period having extremely restrictive regulations, survived at a higher rate than redheads banded during earlier periods when this species was not afforded special protection. The recovery rates were observed during different hunting seasons having quite different shooting pressures and, therefore, cannot serve as a basis for computing survival rates. However, the consistently higher recovery rates in 1964 indicate that more redheads lived to be taken five seasons after banding during the period with very restrictive regulations than during that with more liberal regulations. The difference may have been even greater than shown because

fifth season rates for earlier periods were obtained under more liberal hunting regulations and when the band reporting rate was probably higher than in 1964.

Example 22 illustrates how the relative recovery rate method can be used to compute the survival rate relating to a substantial interval of time. In this instance, recovery rates from the 1964 hunting season were compared for samples of canvasbacks banded after the hunting season during the winters of 1957, 1959 and 1964. This comparison indicated a 21 percent survival rate between 1957 and 1964 and a 34 percent survival between 1959 and 1964. From these estimates it was possible to compute that annual survival rates during this period of very restrictive regulations were about 80 percent. These estimates of survival may be biased on the low side. Longwell and Stotts (1958) found that young canvasbacks, banded during the winter following their first hunting season, were more vulnerable to shooting and had substantially higher recovery rates during their second hunting season than did birds that were older when banded. Since the samples banded and recovered in 1964 no doubt contained many birds that hatched in 1963, the recovery rate may have been somewhat inflated in comparison with rates for birds banded in prior years, which would have been at least 5 years old when recovered in 1964. This may have introduced a small bias due to age composition of the banded samples; thus, survival during the closed seasons may have been even better than the estimates in Example 22 suggest.

Most estimates of annual rates of survival are based on summaries of data similar to that illustrated in Example 23. This table shows the number of recoveries occurring in the first, and each subsequent hunting season after banding for samples banded over a substantial span of time. Data such as these can be used to construct life tables to serve as a basis of mortality estimates, as will be discussed later.

Example 24 shows the computation of a mortality rate estimate using a composite relative recovery rate method based on data in Example 23. This estimate is based on a comparison of recovery rates occurring during the same hunting seasons for the various banded samples. For example, the average annual mortality rate between banding periods based on banding in the winters of 1950 and 1951 was determined by comparing recovery rates during the second through fourteenth hunting seasons (2-n) for birds banded in 1950-51, with the recovery rate during the first through thirteenth hunting seasons (1-n) for birds banded in 1951-52. This yielded an estimated average annual survival of .727. This was done for successive pairs of banding years and provided a basis for computing a composite average mortality rate for the entire span of time based on either the sum of the recovery rates for the periods 1 through n and 2 through n or on an average of the individual survival rate estimates obtained for each 2-year comparison. Both procedures are followed in Example 24. The appropriate one to use depends on the circumstances present in the data. When the average survival rate is based on dividing the sum of recovery rates

1-n into the sum of 2-n, the overall average is influenced more by the early years than the later years because more recoveries have accumulated. This effect is lessened when individual survival rates are averaged, but the average value obtained will be meaningful only if the individual survival rates are fairly constant over the entire span of years considered. In Example 24 both methods for obtaining the average yielded similar estimates.

It should be emphasized that the relative recovery rate method assumes that the same population is sampled during each of the periods considered and that recovery rates are the result of identical shooting pressure having been applied to each of the banded samples. Before this method is used to estimate survival rates, it is a good idea to examine the geographic distribution of recoveries each hunting season after banding to see if each banded sample is being harvested in the same areas during the same season. If they are not, there is reason to suspect that the samples will not be receiving the same shooting pressure and, therefore, the mortality rate estimates will be biased. An important limitation of this approach is that, for birds banded as immatures, first hunting season recovery rates cannot be compared with second hunting season recovery rates to yield an estimate of mortality rate. This is because of the greater vulnerability of immatures to shooting. In instances such as this it is necessary to substitute first hunting season recovery rates from birds banded as adults in making the comparison. Also, when making first-year mortality estimates for birds banded as immature, the recovery rates for later years should not be compounded, i.e., added together as illustrated in Example 24.

Life tables

Summaries of the number of recoveries occurring during various periods of time after banding, commonly called life tables, are frequently used as a basis of estimating annual mortality rates. These estimates can be treated either "dynamically" or "time-specifically," to use the terminology of Hickey (1952) and Farner (1955). Readers are referred to these references for discussions of the use of life tables in studying bird population dynamics. Often in preparing life tables for migratory birds a sufficient period of time has not elapsed to permit all recoveries to be reported that will eventually occur. Example 23 illustrates this situation for Canada geese: at the time these data were summarized, only 344 birds had been banded long enough to yield recoveries 14 hunting seasons after banding, while 4,052 birds had been banded long enough to yield recoveries the first year after banding. In cases like this, the number of recoveries occurring at various periods after banding must be expressed in terms of a common base in order to be comparable. In Example 23 this was done by dividing the number of recoveries during a particular hunting season by the number of birds that had been banded long enough to yield recoveries during that season (banded birds available), and multiplying by 1000 to obtain the number of recoveries per 1000 birds banded.

464-285 O - 72 - 3

Annual mortality estimates are made in Example 23 using a composite dynamic analysis. It is composite because several years data are combined. With this procedure, the total recoveries per thousand birds banded represents total deaths in the population. The distribution of recoveries by years after banding reflects the distribution of deaths throughout time. This method assumes that information is available for the entire lifespan of the species under consideration. If sufficient time has not elapsed to have recoveries representing the entire lifespan, the resulting mortality estimates will tend to be exaggerated since the calculations will, in effect, assume that all the mortality that was going to occur had occurred during the interval for which data were available. Mortality rate during the first year is calculated by dividing the number of recoveries per thousand banded in that year (the number dying) by the number of recoveries per thousand banded in all years (the number alive). Similarly, mortality rate for each subsequent year is obtained by dividing number dying by number alive going into that year. The number alive in each year is obtained by subtracting previous deaths from previous number alive. The average mortality rate for all years is computed by dividing the total recoveries per thousand birds banded minus recoveries during the last year by total alive for all periods minus the number alive in the last year. (In Example 23 these values are shown in parenthesis underneath the totals for the respective rows.) Data for the last year are subtracted from the totals since this year shows 100 percent mortality which is, in fact, a sampling error. In the event that there are gaps in the data for years preceding the last year, values from the last year should be included to counterbalance the period(s) of implied 100 percent survival caused by the year(s) having no recoveries. The deletion of the "last year" in calculating annual mortality rates has much more influence on estimates relating to a short-lived species with data for only a few years (Example 25) than a long-lived species with data relating to many years such as Example 23.

The time specific approach for estimating survival rates assumes that the number of recoveries per thousand birds banded that occurs each year reflects the size of the population living long enough to enter that year. The calculations used in the dynamic and time specific method both are illustrated in Example 25. In the time specific approach, the number of deaths occurring during an annual interval is obtained by subtracting the number of recoveries one year from the number of recoveries that occurred during the preceding year. Thus, the difference in the number of recoveries occurring each year is used to reflect the number of deaths occurring during the year. This approach does not require that data for the entire lifespan of the species be available. It is important to recognize that the time specific method assumes that the number of recoveries obtained during a year is proportional to the size of the population that year, while a dynamic approach assumes that the number of recoveries is proportional to the total deaths occurring during the year. For most heavily shot game species, the dynamic method is preferred. This is especially true when varying shooting pressures cause a larger number

of recoveries from a given year of banding to occur during a later hunting season than one occurring shortly after banding. For example, 100 recoveries might be reported the second year after banding while 125 might be reported the third year.

Estimating effect of hunting mortality on non-hunting and total mortality rates

As mentioned earlier, an important outcome of a banding program is to provide a basis for examining the effect the hunting mortality has on total mortality. This can be done by comparing recovery rates, an index to hunting mortality, with annual mortality rate estimates for different time periods or populations as in Example 17. Example 26 is an elaboration of the graph shown in Example 17. Line A-D shows mortality rate at various rates of recovery. By extrapolating to the point of zero recovery rate, it is estimated that the annual mortality rate would be .40 in the absence of hunting. Then from various points along line A-D, it is possible to subtract the kill rate (band recovery rate adjusted for non-report of bands and crippling loss) that corresponds to the recovery rate at that point. This permits the establishment of line D-C which represents the level of non-hunting mortality under various shooting pressures. The distance between B-D and line A-D for each recovery rate reflects the extent to which hunting mortality is added to that which would have occurred without shooting pressure. The distance between line B-D and C-D indicates the extent to which non-hunting mortality was replaced by hunting mortality, while the distance between B-D and A-D represents the extent to which shooting mortality increased the total mortality rate.

The accuracy with which the several relationships illustrated in Example 26 are measured depends upon how well a number of assumptions are met. Probably most important is the assumption that recovery and mortality rate estimates from each banded sample in the comparison accurately reflect the shooting mortality and annual mortality experienced by each population. Since both the recovery rate and mortality rate estimates are based on some of the same data, the two values plotted are not independent. It can be argued that Example 26 illustrates that the basic assumption underlying the composite dynamic method for estimating mortality rates is not met, i.e., the harvest rate constitutes the same fraction of all deaths each year after banding since under heavy shooting pressures Example 26 clearly indicates that hunting accounts for a higher fraction of total deaths than under light shooting pressures. It must be recognized, however, that the various points used to establish the relationship between shooting pressure and mortality rates (Example 17) relate to different populations banded in different parts of North America. Those populations which have a high hunting mortality the first year after banding and, therefore, a high band recovery rate, will be utilizing areas in subsequent years that also have high hunting pressures; consequently, hunting mortality will continue to be a relatively significant factor.

An analysis of black duck banding data (Geis et al., 1971) showed that samples with high first season recovery rates had relatively low second year rates. This suggests that populations with high recovery rates have relatively high mortality rates. Geographic and chronologic variation in band reporting rates, among other factors, might affect both recovery and mortality rate estimates. Thus, the relationships shown in Example 26 may be imprecise.

Despite these potential problems, this approach has been followed to predict the probable effects of various mallard shooting pressures with reasonable success when population levels going into a hunting season were accurately known (Geis et al., 1969). It is interesting to note that Example 26 is a graphic presentation of the same relationship described for understanding fish populations by Ricker (1958:25) with the formula: $a = m + n - mn$, where a = the total annual mortality rate, m = "hunting" mortality rate and n = the "non-hunting" mortality rate. By providing a basis for estimating the effect of hunting mortality on annual mortality rates, banding provides information vital for migratory game bird management.

GENERAL PRINCIPLES

It cannot be emphasized too strongly that banded birds are merely a sample representing a population of some species. This has a number of important implications. First, it is desirable to know the size of the population represented by banding and the geographic area it occupies. Much more can be done with the banding data if the portion of the continental population represented by the bandings is known. This emphasizes the importance of relating banding data to population survey data. However, banding species for which population data is not available is still worthwhile. For example, the banding of wood ducks and black ducks before the hunting season provides valuable information despite a lack of population data.

Care should be taken to insure that the birds banded reflect the characteristics of the population from which they are taken. There are several considerations here. First, the banded sample should be distributed throughout the population in a representative manner. This, for example, prompted the breeding ground banding program for locals (flightless young ducks) to be distributed throughout the breeding grounds rather than concentrated in a few localities. Also, the banded birds should reflect the survival characteristics of the unbanded members of the population they represent. The trapping and banding process should be one that does not increase the mortality rate of the birds. Methods of capture or handling that result in birds being released in a weakened condition should be avoided. Furthermore, banded birds should not have conspicuous marks which affect their shooting pressure. Color marking destroys the value of band recoveries from many waterfowl. Not only do conspicuous color marks possibly alter shooting pressure, but also they distort the

band reporting rates. The first step in many studies of banding data is the identification of the populations having different distribution and survival characteristics. It is essential that the banded birds accurately reflect the characteristics of these populations.

REFERENCES

Anderson, D. R., and C. F. Kimball.
1969. Summary of first-hunting-season recovery rates of mallards banded in the winter, summer and early fall, 1967 and 1968. Admin. Report 177. Migratory Bird Populations Station, Laurel, Maryland. 10 p.

Ballou, R. M., J. R. Grieb, and A. D. Geis.
1964. Progress report - experimental hunting season San Luis Valley, 1963. Admin. Report 49, Migratory Bird Populations Station, Laurel, Maryland. 7 p.

Croft, R. L., and S. M. Carney.
1969. Sex ratio of ducks killed during the 1968-69 hunting season compared with those of prior years. Admin. Report 170. Migratory Bird Populations Station, Laurel, Maryland. 16 p.

Farner, D. S.
1955. Bird banding in the study of population dynamics. In Recent studies in avian biology, A. Wolfson (ed.). Univ. of Ill. Press, Urbana. p. 397-449.

Geis, A. D.
1959. Annual and shooting mortality estimates for the canvasback. J. Wildl. Mgmt., 23(3): 252-261.

__________.
1966. Information needed and procedures for establishing status of the wood duck population. Wood Duck Management and Research: Symp. Wildlife Management Institute, Washington, D. C. p. 183-192.

__________.
1970. Sex ratio in the mallard population. Unpublished report filed at Migratory Bird Populations Station, Laurel, Maryland.

__________.
1972. Use of winter banding data and kill surveys to monitor Canada goose populations. Transactions of the Fourth Canada Goose Ecology Seminar, W. K. Kellogg Bird Sanctuary, Augusta, Michigan, April 20, 1970 (in press).

__________, and W. F. Crissey.
1969. Effect of restrictive hunting regulations on canvasback and redhead harvest rates and survival. J. Wildl. Mgmt., 33(4): 860-866.

__________, R. K. Martinson, and D. R. Anderson.
1969. Establishing hunting regulations and allowable harvest of mallards in the United States. J. Wildl. Mgmt., 33(4): 848-859.

Geis, A. D., R. I. Smith, and J. P. Rogers.
1971. Black duck distribution, harvest characteristics, and survival. U. S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report--Wildlife No. 139. 241 p.

Hickey, J. J.
1952. Survival studies of banded birds. U. S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report--Wildlife No. 15. 177 p.

Kiel, W. H., Jr.
1959. Mourning dove management units. U. S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report--Wildlife No. 42. 24 p.

Lauckhart, J. B.
1956. Calculating mortality rates for waterfowl. Murrelet, 37(3): 31-34.

Lensink, C. J.
1964. Distribution of recoveries from bandings of ducklings. U. S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report--Wildlife No. 89. 146 p.

Lincoln, F. C.
1930. Calculating waterfowl abundance on the basis of banding returns. U. S. Dept. of Agriculture Circular No. 118. p. 1-4.

Longwell, J. R., and V. Stotts.
1958. Some observations on the recovery of diving ducks banded in the Maryland portion of Chesapeake Bay. Proc. Annual Conf. Southeastern Assoc. Game and Fish Commissioners 12: 285-291.

Martinson, R. K.
1966a. Some characteristics of wintering mallard populations and their management. Admin. Report 116. Migratory Bird Populations Station, Laurel, Maryland. 11 p.

__________.
1966b. Proportion of recovered duck bands that are reported. J. Wildl. Mgmt., 30(2): 265-268.

Reeves, H. M.
1969. A preliminary report - preseason mourning dove bandings, recoveries, recovery rates, and mortality rates, Eastern Management Unit, 1965-1967. Unpublished ms. filed at Migratory Bird Populations Station, Laurel, Maryland.

Ricker, W. E.
1958. Handbook of computations for biological statistics of fish populations. Fisheries Research Board of Canada Bulletin No. 119: 128-129.

Rutherford, W.
1970. Canada geese of southeastern Colorado. Unpublished ms. on file Division of Game, Fish and Parks, Game Research Center, Fort Collins, Colorado.

Smith, R. I.
1963. Lesser scaup and ring-necked duck shooting pressure and mortality rates. Admin. Report 20. Migratory Bird Populations Station, Laurel, Maryland. 18 p.

Example 1.--Direct recoveries of mallard locals banded in various breeding population census strata (from Lensink, 1964)

Region of banding (survey stratum)	Number recovered	Recoveries by flyway (percent)							
		Atlantic	Miss.	Central	Pacific	Alaska	Canada	So. of the U. S.	Total
(03) Alaska	35			2.8	31.4	22.8	42.8		99.8
(13) Alberta	10			10.0	10.0		80.0		100.0
(26) Alberta	510		7.8	11.2	26.5		54.5		100.0
(27) Alberta	442		16.1	13.3	11.5		59.0		99.9
(28) Alberta	31		6.4	19.4	29.0		45.2		100.0
(16) Saskatchewan	24		37.5	12.5			50.0		100.0
(19) Saskatchewan	1679	0.8	32.9	23.8	4.5		37.8	0.2	100.0
(20) Saskatchewan	596	0.7	36.4	18.3	0.3		44.3		100.0
(21) Saskatchewan	503	0.8	33.8	15.3	2.0		48.1		100.0
(22) Saskatchewan	474	1.9	44.1	13.3	0.2		40.5		100.0
(23) Saskatchewan	91		25.3	31.9	8.8		34.1		100.1
(17) Manitoba	14		35.7				64.3		100.0
(24) Manitoba	259	1.9	29.7	11.6			56.8		100.0

464-28, O - 72 - 4

Example 2.--Distribution of band recoveries from mallards banded in Washington and Arkansas during January and February 1964, and recovered during the 1964-65 hunting season

	Columbia Basin portion of Washington		Arkansas	
	Number of recoveries	Percent	Number of recoveries	Percent
Alaska	1	1.1		
Canada				
British Columbia	3	3.2		
Alberta	9	9.6	11	3.6
Saskatchewan			7	2.3
Manitoba			10	3.3
Ontario			1	0.3
Pacific Flyway				
Washington	69	73.4		
Oregon	9	9.6		
Idaho	2	2.1		
Montana (W)	1	1.1		
Central Flyway				
Montana (E)			1	0.3
North Dakota			19	6.3
South Dakota			8	2.6
Nebraska			5	1.6
Kansas			1	0.3
Oklahoma			1	0.3
Texas			4	1.3
Mississippi Flyway				
Minnesota			38	12.6
Wisconsin			7	2.3
Iowa			13	4.3
Illinois			24	7.9
Indiana			1	0.3
Missouri			21	7.0
Kentucky			1	0.3
Tennessee			8	2.6
Arkansas			86	28.5
Louisiana			19	6.3
Mississippi			16	5.3
Total	94	100.1	302	99.6
Percent of recoveries in State of banding		73.4		28.5
Band recovery rate (percent of banded birds recovered)		5.95		6.01

Example 3.--Breeding ground derivation of the kill of immature black ducks in Tennessee and Massachusetts based on weighted band recoveries (from Geis *et al.*, 1971)

Breeding area	Harvest Area	
	Tennessee Origin of kill (in %)	Massachusetts Origin of kill (in %)
New Brunswick		6.7
Newfoundland		11.3
Nova Scotia		8.2
Labrador		9.8
Quebec		45.9
Maine		8.4
New Hampshire		1.1
Vermont		0.2
Massachusetts		7.8
Connecticut		0.1
New York	1.6	0.4
Ontario	45.9	
Michigan	44.0	
Wisconsin	7.1	
Minnesota	1.3	
	99.9	99.9

Example 4.--Example of one way of estimating the weight to be given each black duck band recovery from wintering area bandings (from Geis et al., 1971).

	Wintering area		
	Long Island east of 73°	Maine	La., Ark. & Miss.
A. Average wintering population 1950-58	12,200	11,000	22,490
B. Total recoveries	645	111	16
C. Population per recovery (A ÷ B)	18.9	99.1	1,405.6
D. First-hunting-season recovery rate	.061	.050	.065
E. Total kill per recovery (weight C x D)	1.2	5.0	91.4

Example 5.--Factors for weighting mourning dove banding data (from Kiel, 1959)

State	(A) Average calls per route*	(B) Est. dove habitat (sq. mi.)	(C) Dove index (A) X (B)	(D) Doves banded	Weighting factor (C) ÷ (D)
Ala.	20.0**	51,078	1,022,000	1,395	733
Ariz.	37.0	113,580	4,202,000	9,169	459
Ark.	28.0	52,725	1,476,000	592	2,493
Calif.	33.6	141,123	4,742,000	7,628	622
Colo.	41.5	72,777	3,020,000	371	8,140
Conn.	7.3	3,919	29,000	166	175
Del.	30.8	1,978	61,000	117	521
D. C.	No index			4	
Fla.	15.3	54,262	830,000	3,953	210
Ga.	19.4**	58,518	1,135,000	175	6,486
Idaho	30.4	49,685	1,510,000	710	2,127
Ill.	23.3	55,947	1,304,000	4,868	268
Ind.	36.7	36,205	1,332,000	2,535	525
Iowa	45.8	55,986	2,564,000	3,184	805
Kansas	40.0	92,113	3,684,000	1,876	1,964
Ky.	20.1**	40,109	806,000	3,164	255
La.	24.0	45,177	1,084,000	13,777	79
Md.	20.6	9,393	193,000	87	2,218
Mass.	4.3	1,977	8,000	1,476	5
Mich.	23.2	28,511	661,000	1,031	641
Minn.	35.2	60,007	2,112,000	3,041	695
Miss.	23.8**	47,420	1,128,000	4,645	243
Mo.	47.8	69,270	3,311,000	6,411	516
Mont.	28.4	124,369	3,532,000	104	33,962
Nebr.	50.0	76,653	3,833,000	4,583	836
Nev.	28.2	108,704	3,065,000	203	15,099
N. J.	12.7	7,522	96,000	433	222
N. Mex.	31.1	109,360	3,401,000	1,403	2,424
N. Y.	27.9	11,982	334,000	273	1,223
N. C.	24.5**	44,232	1,084,000	206	5,262
N. Dak.	19.5	70,054	1,366,000	6,172	221
Ohio	20.7	41,122	851,000	4,025	211
Okla.	26.9	69,283	1,863,000	914	2,038
Oregon	31.3	72,263	2,261,000	3,475	651
Pa.	11.0	23,465	258,000	877	294
R. I.	No index			54	
S. C.	25.5**	30,594	780,000	401	1,945
S. Dak.	61.0	73,475	4,482,000	4,188	1,070
Tenn.	28.7**	41,961	1,204,000	646	1,864
Texas	46.2	263,644	12,180,000	12,665	962
Utah	37.0	74,111	2,742,000	489	5,607
Va.	21.9	37,904	830,000	65	12,769
Wash.	43.0	46,884	2,016,000	798	2,526
W. Va.	10.3	16,863	174,000	64	2,718
Wis.	42.0	38,300	1,609,000	782	2,058
Wyo.	13.9	82,080	1,141,000	783	1,457
Total		2,606,585	85,316,000	113,978	

* Average data from 1954 - 1957

**Average of 1957 random call-count routes only

Example 6.--Use of weighted band recoveries to indicate the breeding area derivation of the immature mallard kill in Arkansas and Washington based on preseason banding, 1966-68 (from files, MBPS)

Arkansas as a Recovery Area:

Breeding area*	No. of recoveries (A)	Weighting factor (B)	Weighted recovery total (A x B)	Origin of kill (in %)
Northwest Territories	2	3,793	7,586	6.7
Alberta	8	1,879	15,032	13.3
Saskatchewan	44	1,477	64,988	57.6
Manitoba	10	726	7,260	6.4
Ontario	15	40	600	0.5
Montana	3	228	684	0.6
North Dakota	5	1,329	6,645	5.9
South Dakota	19	444	8,436	7.5
Minnesota	36	35	1,260	1.1
Wisconsin	20	9	180	0.2
Totals	162		112,671	99.8

Washington as a Recovery Area:

Breeding area	No. of recoveries (A)	Weighting factor (B)	Weighted recovery total (A x B)	Origin of kill (in %)
Northwest Territories	3	3,793	11,379	13.5
British Columbia	2	3,361	6,722	7.9
Alberta	21	1,879	39,459	46.7
Saskatchewan	1	1,477	1,477	1.7
Washington	193	121	23,353	27.6
Oregon	15	80	1,200	1.4
Idaho	3	95	285	0.3
Montana	3	228	684	0.8
Totals	241		84,559	99.9

* Six breeding areas contributing less than 0.1% of total kill omitted in Arkansas.

Example 7.--Comparison of the distribution of the black duck hunting kill in the United States based on various sources of information (from Geis et al., 1971)

State of kill	Weighted band recoveries: Summer bandings: Adults	Weighted band recoveries: Summer bandings: Ages combined	Weighted band recoveries: Winter bandings: Adults	Mail questionnaire survey: Mean - 1954-60
Maine	5.0	4.4	3.1	5.3
Vermont	1.2	1.2	0.9	0.8
New Hampshire	0.3	0.5	0.3	1.1
Massachusetts	7.1	5.2	2.8	6.9
Connecticut	2.9	4.3	1.6	2.3
Rhode Island	1.3	1.4	1.6	1.9
New York	12.3	12.1	7.3	13.8
Pennsylvania	1.5	3.8	3.4	3.5
West Virginia	0.2	0.2	0.3	0.2
New Jersey	20.6	17.8	17.0	7.9
Delaware	5.4	4.9	3.2	3.4
Maryland	16.3	11.4	15.9	4.7
Virginia	7.0	5.9	3.3	3.6
North Carolina	1.9	2.5	1.7	2.4
South Carolina	1.7	2.0	1.6	1.0
Georgia	0.2	0.1	T	0.2
Florida	0.3	0.5	0.3	2.0*
ATLANTIC FLYWAY	85.2	78.2	64.3	61.1
Minnesota	0.2	0.3	1.2	3.6
Wisconsin	1.3	2.8	5.0	6.0
Michigan	5.0	7.3	5.5	10.9
Iowa	0.1	0.1	0.4	0.4
Illinois	0.8	1.4	4.8	1.9
Indiana	1.4	1.3	1.4	1.5
Ohio	2.4	4.8	8.8	4.3
Missouri	T	0.1	T	0.5
Kentucky	0.9	0.7	2.0	0.9
Arkansas	0.3	0.7	2.6	1.1
Tennessee	1.2	1.2	2.6	1.6
Louisiana	0.1	0.2	0.4	4.6*
Mississippi	0.4	0.4	0.1	0.4
Alabama	0.8	0.6	1.0	0.9
MISSISSIPPI FLYWAY	14.9	21.9	64.3	61.1

* Kill survey combined mottled and Florida ducks with black ducks.

Example 8.--Distribution of indirect recoveries of Canada geese by State and Province of recovery from banding in southern Illinois during the hunting seasons of 1959 - 1963 (from files MBPS)

State or Province	Recoveries	Percent of total recoveries
Manitoba	2	0.6
Ontario	20	5.6
Quebec	1	0.3
Northwest Territories	1	0.3
CANADA	24	6.8
Pennsylvania	2	0.6
Maryland	2	0.6
North Carolina	1	0.3
ATLANTIC FLYWAY	5	1.4
Minnesota	5	1.4
Wisconsin	159	44.8
Michigan	41	11.5
Iowa	5	1.4
Illinois	85	23.9
Indiana	7	2.0
Ohio	1	0.3
Missouri	10	2.0
Kentucky	7	2.0
Tennessee	4	1.1
MISSISSIPPI FLYWAY	324	91.3
South Dakota	1	0.3
CENTRAL FLYWAY	1	99.8
TOTAL RECOVERIES	355	99.8

Example 9.--Recovery rates as a measure of shooting pressure against canvasbacks based on birds of both sexes banded post season during the winter and spring (from Geis and Crissey, 1969 and Geis, 1959)

Banding area	Hunting seasons of recovery	Regulations: Season length	Regulations: Bag limit	Number banded	1st Season recovery rate
New York	1952-1957	55-70 days	4	6,736	8.1
	1958	60 "	2	2,353	12.3
	1959	50 "	1	943	0.9
	1960-1963	closed	0	2,690	0.2
	1964-1965	40-50 days	2	1,039	6.3
Michigan	1948-1950	30-40 days	4	858	2.7
	1951-1955	45-70 "	4	1,286	5.6
	1960-1963	closed in U.S.		1,222	0.3

Relationship of hunting regulations to first hunting season recovery rates of ring-necked ducks banded in winter and spring in South Carolina and Louisiana (from Smith, 1963)

Banding area	Years	Number banded	Season length (days)	Recovery rate	Relationship*
South Carolina	27-30	48	92	12.5	
	31	202	30	5.4	+
	40-41	234	60	3.8	
	42-43	30	70	6.7	+
	47-51	333	30-45	2.7	+
	53-58	435	60-70	8.5	+
	59-61	399	40	5.3	+
Louisiana	29-30	99	92	14.1	
	31	102	30	3.9	+
	32-33	419	61	7.2	+
	34-37	2,003	30	4.9	+
	38	234	45	3.4	-
	40-41	365	60	4.7	+

* Plus indicates rate and season length change in same direction.

Example 10.--Use of band recovery rates to measure age differences in vulnerability. Recovery rates and age ratios relate to mallards banded preseason and shot in the experimental season in the San Luis Valley of Colorado (from files MBPS)

Year	Age	Recovery rate	Relative rec. rate (imm.rate ÷ adult rate) (A)	Age ratio in kill* (imm/ad) (B)	Age ratio in pop. (imm/ad) (B) ÷ (A)
1963	Ad.	.040	1.0	0.80	.80
	Imm.	.040			
1964	Ad.	.038	1.4	1.21	.86
	Imm.	.053			

*based on wing collection survey

Example 11.--Estimates of the sex composition of the North American mallard populations in 1967 and 1968 (files MBPS)

Information and source	Adult based on:				Immature based on:	
	Post season winter banding		Preseason banding		Preseason banding	
	1967	1968	1967	1968	1967	1968
1. Sex ratio in U.S. kill (1) males/female (Croft & Carney, 1969)	1.92	2.16	1.92	2.16	1.23	1.33
First season band recovery rate in U.S. (Geis, 1970b, and Anderson & Kimball, 1969)						
2. Male (2)	.0453	.0344	.0383	.0312	.0494	.0392
3. Female (3)	.0306	.0183	.0316	.0195	.0389	.0313
4. Extent to which males were more likely to be harvested than females (2 ÷ 3)	1.480	1.880	1.212	1.600	1.270	1.252
5. Sex ratio in population at time of banding, males/female (1 ÷ 4)	1.30	1.15	1.58	1.35	0.97	1.06

Example 12.--Average first-hunting-season band recovery rates and annual mortality rates for mallards banded during the winter in several regions, 1950-1964 (from Martinson, 1966a)

Wintering area	Average first-hunting-season recovery rate		Average annual mortality rate	
	Males	Females	Males	Females
Western Washington	.074	.046	.433	.339
Western Oregon	.107	.080	.405	.479
Eastern Washington	.068	.041	.392	.442
Northeastern Oregon	.059	.041	.360	.454
Southern Idaho	.048	.039	.340	.431
Southeastern Oregon	.065	.049	.352	.458
Central California	.061	.043	.361	.430
Western Montana	.062	.048	.403	.417
Central Montana	.040	.032	.363	--
Eastern Montana	.041	.028	.362	.441
Northern Wyoming	.046	.039	.356	.470
Southeastern Wyoming	.077	.074	.381	.476
Western Colorado	.060	.040	.394	.429
Southeastern Colorado	.033	.026	.291	.373
Oklahoma	.078	.059	.425	.514
Eastern South Dakota	.036	.031	.313	.493
Eastern Nebraska	.086	.073	.405	.480
Western Missouri	.046	.030	.343	.346
Northwestern Illinois	.076	.039	.496	--
Southern Illinois	.063	.046	.395	.471
Southern Arkansas	.062	.044	.338	.406
Mississippi	.062	.040	.435	--
Northern Indiana	.073	.046	.394	.448
Central Tennessee	.075	.046	.416	--
Eastern Tennessee	.061	.038	.476	.424
Northern Alabama	.055	.051	.305	.493
South Carolina	.058	.034	.398	.396
Eastern Pennsylvania	.067	.064	.346	.450
Delaware	.055	.042	.316	.421
Eastern Maryland	.050	.044	.347	.440

Example 13.--Proportion of deaths due to shooting during the year following banding for immature canvasbacks banded in Manitoba and Saskatchewan, 1953-57 (from Geis, 1959)

Reported recovery rate for first-hunting season:	0.22
Reporting rate = 0.63, therefore, harvest rate (.22 ÷ .63):	0.35
Crippling loss = 40 percent bag, therefore, kill rate:	0.49*
Total annual mortality rate:	0.77
Estimated proportion of total death due to shooting (.49 ÷ .77):	0.64

* $\frac{.35}{100} = \frac{x}{140}$

$100x = 49$

Example 14.--Wood duck kill information and estimates of the pre-hunting season population in the Atlantic and Mississippi Flyways, 1963-65 (from Geis, 1966)

		1963	1964	1965	
Retrieved kill (harvest)	Atlantic Flyway	124,800	105,600	154,000	Weighted estimates of the retrieved kill, based on the questionnaire survey results adjusted for response bias.
	Mississippi Flyway	371,100	320,500	337,000	
	Total	495,900	426,100	492,200	
Age ratio in harvest	Atlantic Flyway	1.52	1.59	1.88	From wing survey, expressed as immatures per adult.
	Mississippi Flyway	1.77	1.90	2.26	
	Weighted Average	1.71	1.78	2.13	
Band recovery rates	Adult	0.058	0.044	0.042	Proportion of wood ducks banded in the summer and pre-hunting season period that were recovered in the first hunting season, expressed as a fraction. Weights equally the recovery rate from each State of banding.
	Immature	0.068	0.053	0.054	
Harvest rates	Adult	0.193	0.147	0.140	Observed recovery rates adjusted for non-report of bands, using 0.30 reporting rate.
	Immature	0.227	0.177	0.180	
Retrieved kill by age	Adult	182,990	153,270	157,200	Applying wing survey age ratio to questionnaire survey results.
	Immature	312,910	272,830	335,000	
Pre-season population estimates	Adult	948,135	1,042,653	1,122,357	Retrieved kill divided by rate of harvest.
	Immature	1,378,458	1,541,413	1,861,111	
	Total	2,326,593	2,584,065	2,983,968	

Example 15.--Estimate of the preseason mallard population associated with the San Luis Valley, Colorado, based on banding 1963 (Ballou *et al.*, 1964)

Information	Source of data	Estimate
Total retrieved kill	Mail Questionnaire Survey	9,492
Age ratio in kill (imm/ad)	Wing Collection Survey	0.8
Harvest by age groups:	Mail Questionnaire and Wing Survey	
Adults		5,273
Immatures		4,219
Harvest rate:	Banding and Mail Questionnaire Survey	
Adult		0.1648
Immature		0.1708
Preseason population estimate:	Harvest divided by harvest rate	
Adults		31,996
Immatures		24,701
	Total	56,697

Example 16.--Estimates of population size in two different banding areas, calculated from the size and rate of harvest in two different harvest areas

		Harvest rate in area:		Harvest in area:	
Banding area	Population	X	Y	X	Y
A	75,000	.06	.03	4500	2250
B	100,000	.02	.06	2000	6000
				6500	8250

In the above situation only the harvest rates and total kill in X and Y would be known. To estimate the size of the population in A and B solve simultaneous equations as follows:

$$.06\,A + .02\,B = 6{,}500$$
$$.03\,A + .06\,B = 8{,}250$$

$$.06\,A + .02\,B = 6{,}500$$
$$(x2)\quad .06\,A + .12\,B = 16{,}500$$

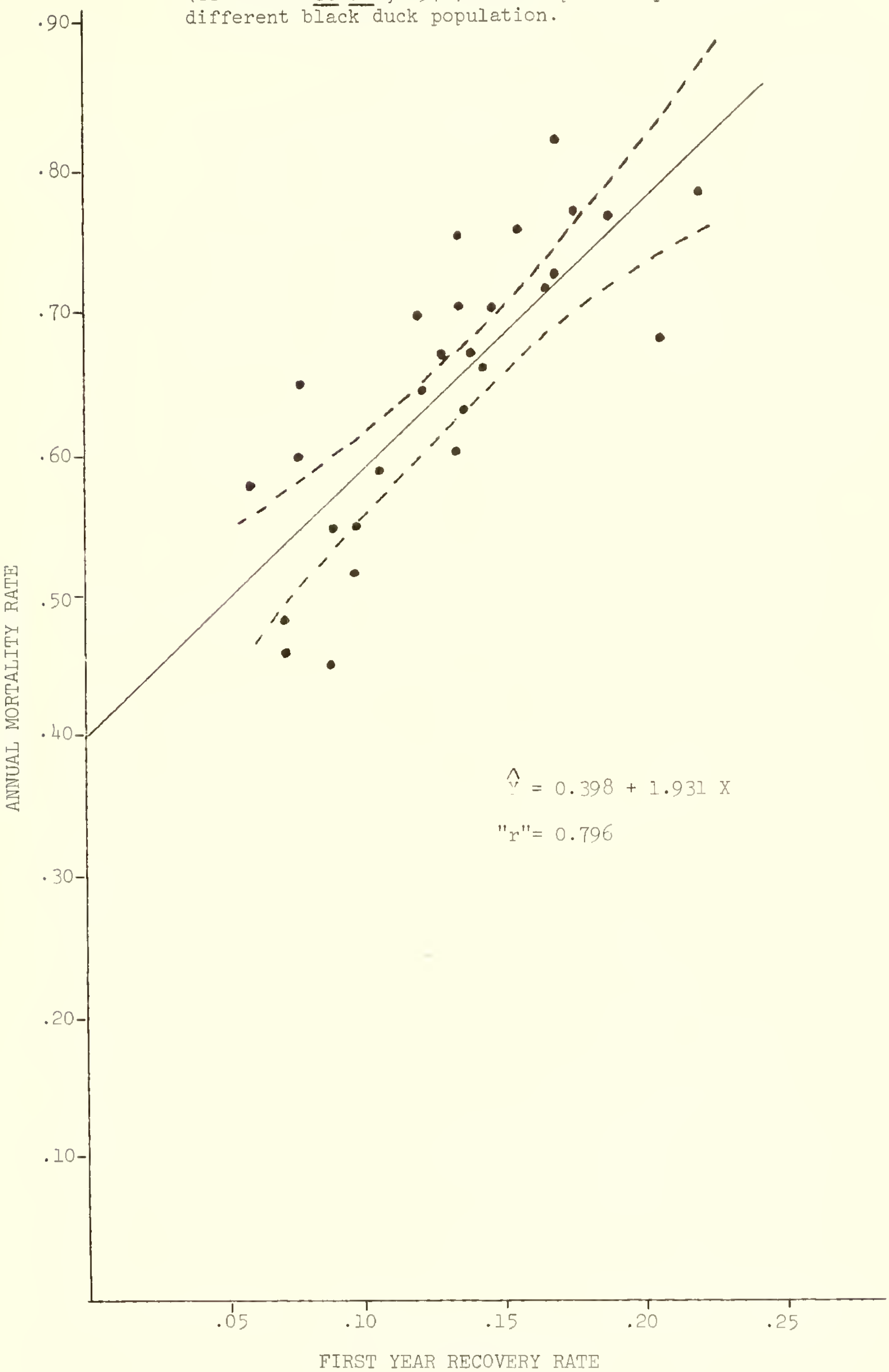
$$-\ .10\,B = -10{,}000$$

Population of area B = 100,000

$$.06\,A + (.02)\,(100{,}000) = 6{,}500$$
$$.06\,A + 2{,}000 = 6{,}500$$
$$.06\,A = 4{,}500$$

Population of area A = 75,000

Example 17.--Relation between annual mortality rate and first year recovery rate of immature black ducks banded before the hunting season in the summer and early fall, 1946-60 (from Geis et al., 1971). Each point represents a different black duck population.



Example 18.--Summary of mourning dove banding and recovery rate data from the 1966 and 1967 preseason (June - August) banding program (from Reeves, 1969)

Mgt. unit	Age when banded	Year	Number banded	Year of recovery 1966 No.	1966 Rate	1967 No.	1967 Rate
Eastern	Immature	1966	26,115	1,720	.0659	199	.0076
		1967	32,314			1,527	.0473
	Adult	1966	11,350	466	.0411	100	.0088
		1967	13,060			478	.0366
Central	Immature	1966	8,654	189	.0218	59	.0068
		1967	15,750			374	.0237
	Adult	1966	6,393	80	.0125	56	.0088
		1967	14,126			227	.0161
Western	Immature	1966	5,706	183	.0321	71	.0124
		1967	4,499			166	.0369
	Adult	1966	4,764	184	.0386	69	.0145
		1967	3,784			92	.0243

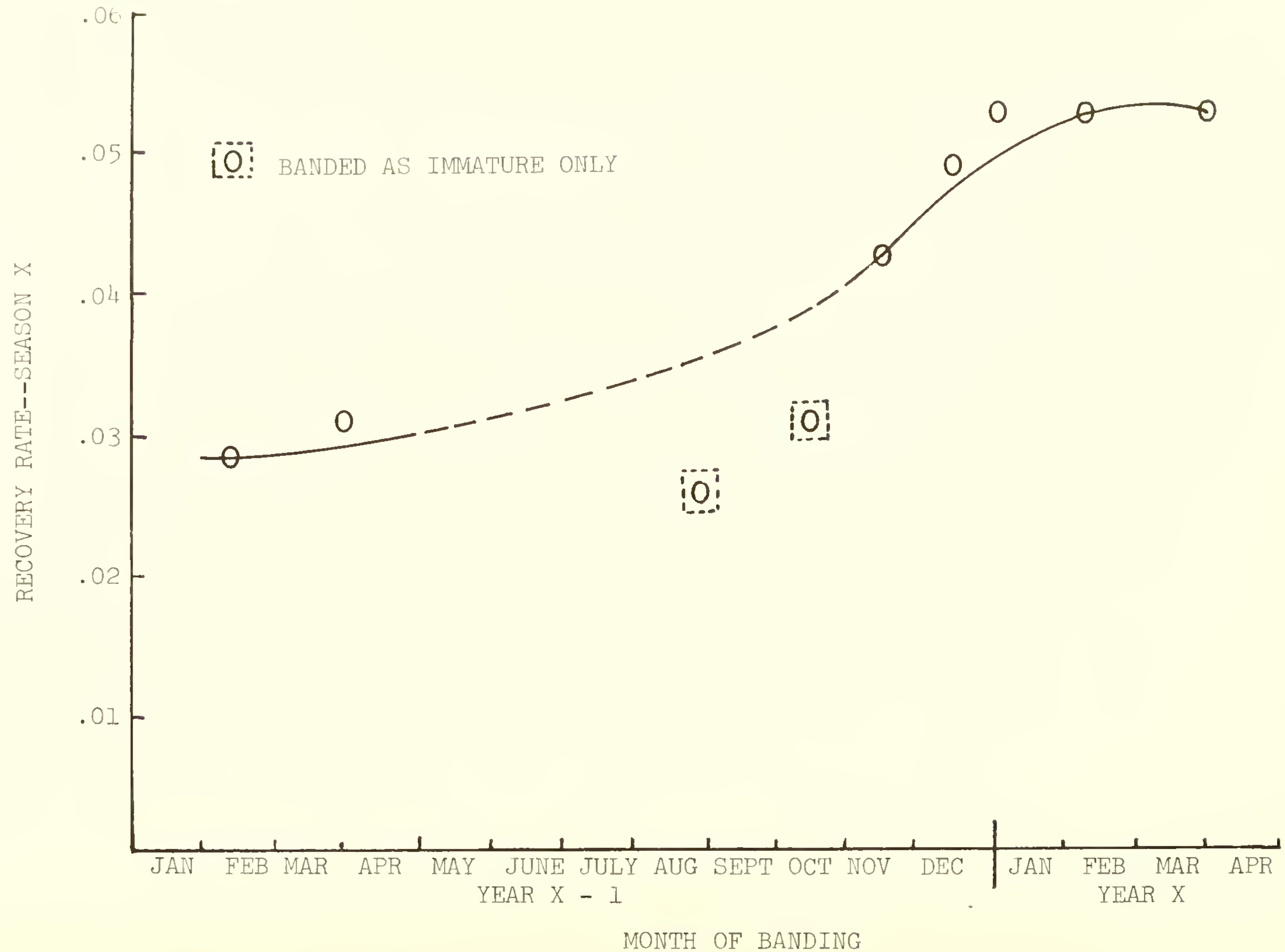
Mortality rate estimates between 1966 and 1967 banding periods:

Age when banded	Mgt. unit	Recovery rates used in estimates (1) 1st Season	(2) 2nd Season	(3) Survival rate (2) ÷ (1)	Mortality rate 1 - (3)
Immature	Eastern	.0366	.0076	.208	.792
	Central	.0161	.0068	.422	.578
	Western	.0243	.0124	.510	.490
Adult	Eastern	.0366	.0088	.240	.760
	Central	.0161	.0088	.547	.453
	Western	.0243	.0145	.597	.403

Example 19.--Comparison of recovery rates from male black ducks banded during different periods within the year (from Geis *et al.*, 1971)

Age when banded	Banding period	Hunting season of recovery	Recovery rate
All ages	Winter	Second	.028
All ages	Spring	Second	.031
Immature	Summer	Second	.026
Immature	October	Second	.031
All ages	November	Second	.042
All ages	December	Second	.049
All ages	January 1-15	Second	.053
All ages	Winter	First	.053
All ages	Spring	First	.053

Example [illegible].--Mortality occurring during the year among male black ducks based on average recovery rates for each banding period. (The values plotted are listed in Example 19.)



Example 21.--Comparison of band recovery rates of redheads banded as locals and recovered during the 5th hunting season following periods of restrictive versus relatively liberal hunting regulations (from Geis and Crissey, 1969)

Banding area	Year of banding	Hunting season(s) of recovery	Number banded	Recovery rate
Alberta	1960	1964	178	.0056
	1940-54	1944-58	264	.0038*
Manitoba	1960	1964	211	.0047
	1951-54	1955-58	758	.0026*
California	1960	1964	503	.0040
	1950-54	1954-58	1,028	.0029*
Utah	1960	1964	631	.0095
	1949-51	1953-55	2,264	.0009*

*Recoveries used to compute these rates were limited to those occurring in the fifth hunting season after banding in the years indicated.

Example 22.--Estimates of annual mortality rates of adult canvasbacks wintering in Maryland and Delaware during a period of restrictive hunting regulations (from Geis and Crissey, 1969).

Year banded	Number banded	1964 Recovery rate	Survival rate during interval (Si)	Length of interval in years (n)	Annual survival rate (Sa)*	Annual mortality rate
1957	1161	.0094	.21	7	.80	.20
1959	459	.0152	.34	5	.80	.20
1964	1881	.0452				

*Calculated from relationship $S_a = S_i^n$ or $\log S_a = \log S_i \div n$.

Example 23.--Banding data from adult Canada geese banded post season in winter at Two Buttes, Colorado, organized for composite dynamic mortality estimates (from Rutherford, 1970)

Winter banded	Number banded	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
		Hunting season of recovery														
50-51	344	45	23	19	10	6	13	3	3	3	2	2	0	0	1	
51-52	650	71	37	23	21	23	3	9	6	10	5	7	5	1		
52-53	900	85	55	47	35	20	19	9	12	8	6	2	3			
57-58	347	37	24	16	8	5	5	1								
58-59	217	22	9	7	4	4	2									
59-60	250	26	16	5	7	2										
60-61	306	29	12	10	9											
61-62	334	31	15	10												
62-63	369	25	18													
63-64	335	16														
Totals	4052	387	209	137	94	60	42	22	21	21	13	11	8	1	1	
Banded birds available		4052	3717	3348	3014	2708	2458	2241	1894	1894	1894	1894	1894	994	344	
Recoveries per 1,000 banded		95.5	56.2	40.9	31.2	22.2	17.1	9.8	11.1	11.1	6.9	5.8	4.2	1.0	2.9	315.9
								217.5								(313.0)*
Alive going in to period		315.9	220.4	164.2	123.3	92.1	69.9	52.8	43.0	31.9	20.8	13.9	8.1	3.9	2.9	1163.1
								844.3								(1160.2)*
Mortality rate		30.2						25.8								27.0

* Values in parenthesis (computed without the last year of recovery) are the basis for the accompanying mortality rate estimate.

Example 24.--Data in Example 23 summarized for use in making relative recovery rate mortality estimates for adult Canada geese banded at Two Buttes, Colorado

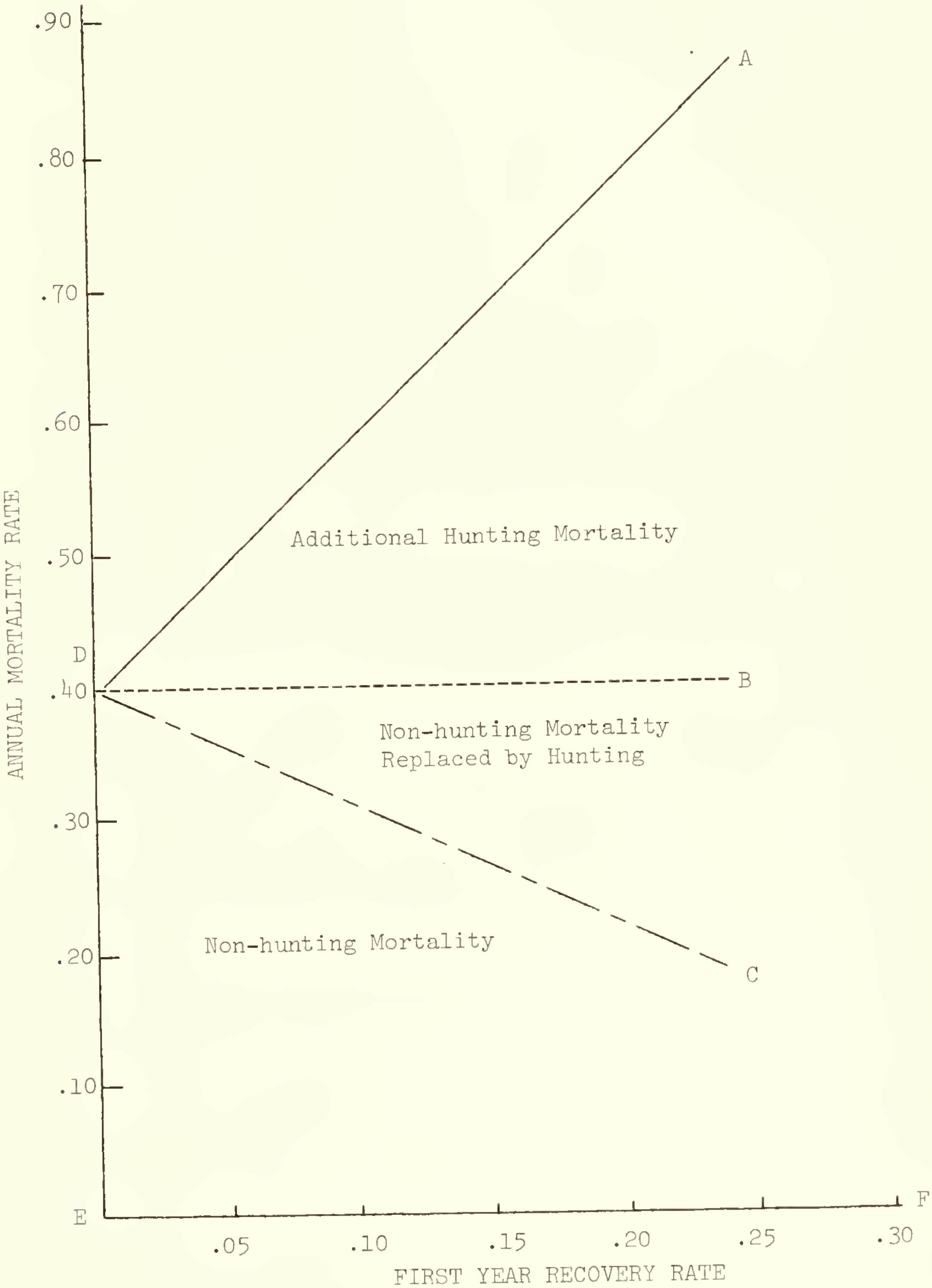
Winter banded	Number banded	Number of recoveries		Recovery rates		Survival rate	Mortality rate
		1-n	2-n	1-n	2-n		
50-51	344	can't use	85	-	.2471		
						.727	.273
51-52	650	221	150	.3400	.2308		
						.690	.310
52-53	900	301	can't use	.3344	-		
57-58	347	can't use	59		.1700		
						.768	
58-59	217	48	26	.2212	.1200		
						.536	
59-60	250	56	30	.2240	.1200		
						.612	
60-61	306	60	31	.1961	.1013		
						.604	
61-62	334	56	25	.1677	.0748		
						.642	
62-63	369	43	18	.1165	.0488		
						1.021	
63-64	335	16	can't use	.0478			
Totals	4052			1.6477	1.1128	5.600	
	Average survival rate				.675	.700	.300
	Average mortality rate				.325	.300	

Example 25.--Composite dynamic and time-specific mortality estimates for canvasbacks banded when immature in Manitoba and Saskatchewan, 1953-57 (from Geis, 1959).

Hunting season after banding	Banded birds "Available"	Number recovered	Recoveries per 1,000 "Available"	Dynamic method: Alive going into period	Dynamic method: Number of deaths	Dynamic method: Mortality rate	Time-specific method: Alive going into period	Time-specific method: Number of deaths	Time-specific method: Mortality rate
1	950	210	221.0	288.4	221.0	.77	221.0	187.7	.85
2	751	25	33.3	67.4	33.3		33.3	15.6	
3	622	11	17.7	34.1 } 117.9	17.7 } 61.1	.52	17.7 } 61.1	7.6 } 27.0	.44
4	495	5	10.1	16.4	10.1		10.1	3.8	
5	316	2	6.3	~~6.3~~	~~6.3~~		~~6.3~~	~~6.3~~	
			288.4	412.6 (406.3)*	288.4 (282.1)	.69	288.4 (282.1)	221.0 (214.7)	.76

* Values in parenthesis (computed without the last year of recovery) are the basis for the accompanying mortality rate estimate.

Example 26.--Relation between hunting, non-hunting and total mortality for immature black ducks banded before the hunting season in the summer and early fall, 1946-60 (from Geis *et al.*, 1971)



U.S. GOVERNMENT PRINTING OFFICE: 1972 O—464-285

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